Baxter & Terrill

Tests of Anthracite Coal
In House Heating Boilers

Mechanical Engineering

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TESTS OF ANTHRACITE COAL IN HOUSE HEATING BOILERS

BY

Charles Bayard Baxter
Fred Terrill

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1908

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June 1, 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CHARLES BAYARD BAXTER FRED TERRILL

ENTITLED TESTS OF ANTHRACITE COAL IN HOUSE HEATING BOILERS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

J. M. Snodgrass
Instructor in Charge.

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TESTS OF ANTHRACITE COAL
IN
HOUSE HEATING BOILERS.

INTRODUCTION.

During the past two years a number of house heating boiler trials have been conducted by the Engineering Experiment Station of the University of Illinois and the Fuel Testing Division of the U. S. Geological Survey for the purpose of establishing a standard method of testing, and determining the relative value of various fuels for use in residence heating boilers. The tests described in this thesis were made in conjunction with those of the Engineering Experiment Station under a Mercer, and an Arco steam heating boiler, located in the Mechanical Engineering Laboratory at the University of Illinois.

PURPOSE OF TEST.

These tests were made to determine the effect of trials of different duration upon the efficiency of the boiler when using anthracite coal as a fuel and the standard method of starting.

DESCRIPTION OF APPARATUS.

BOILERS:- The Arco boiler, made by the American Radiator Co., is shown in Fig. 1. It is a vertical boiler of a round form with a spreading base. The interior circulation is established by three water columns, a section of which is shown in Fig. 2. The fire pot and chamber section, Fig 3, show the

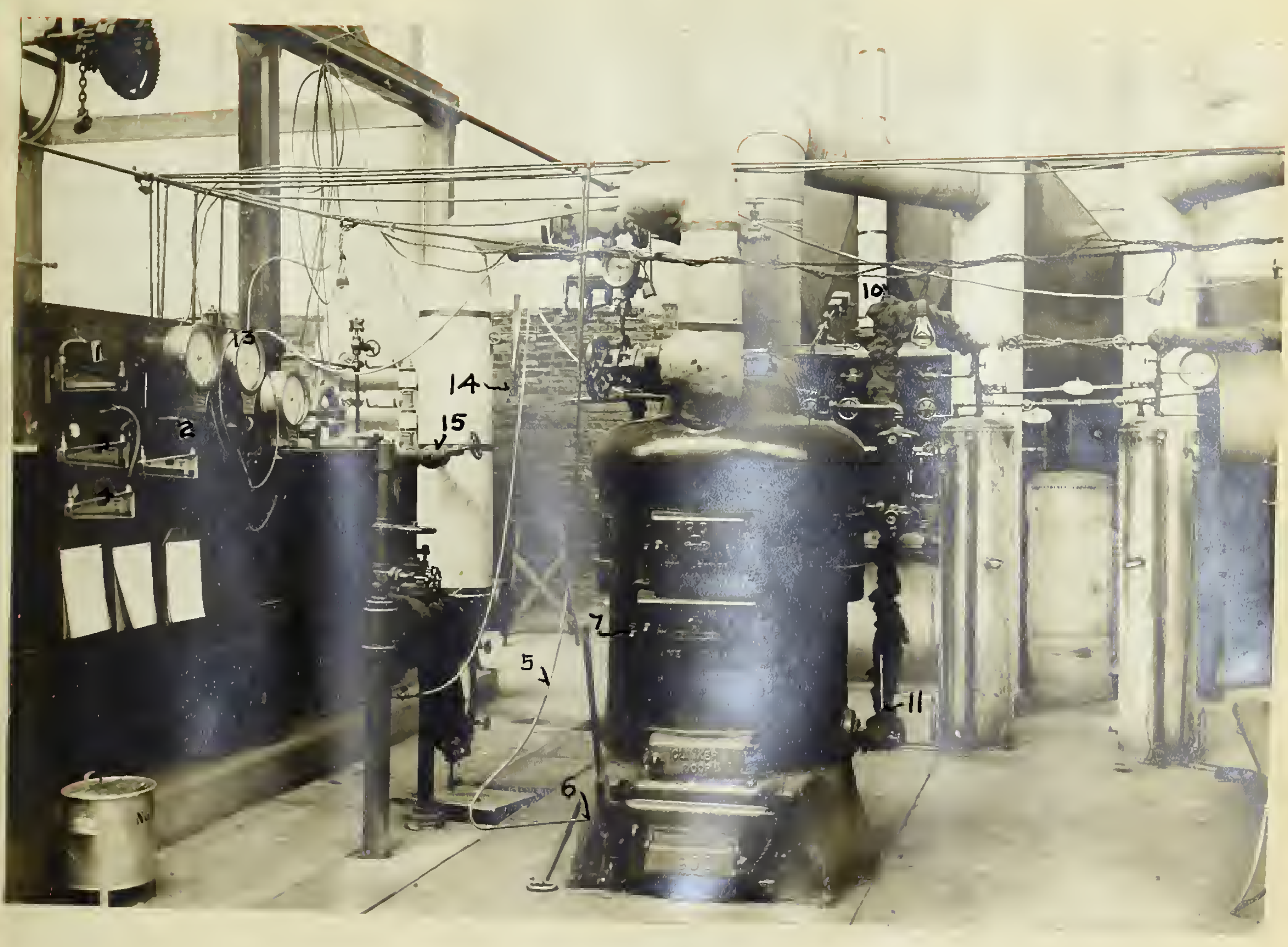
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Figure 1.

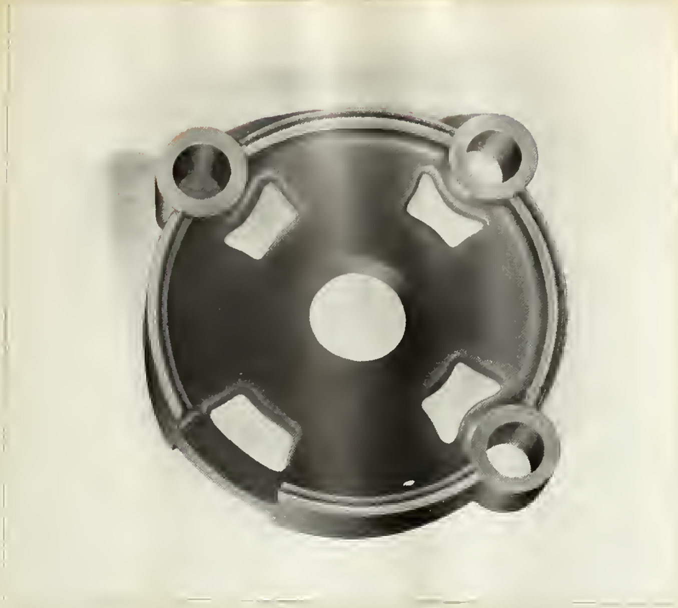

Figure 2.

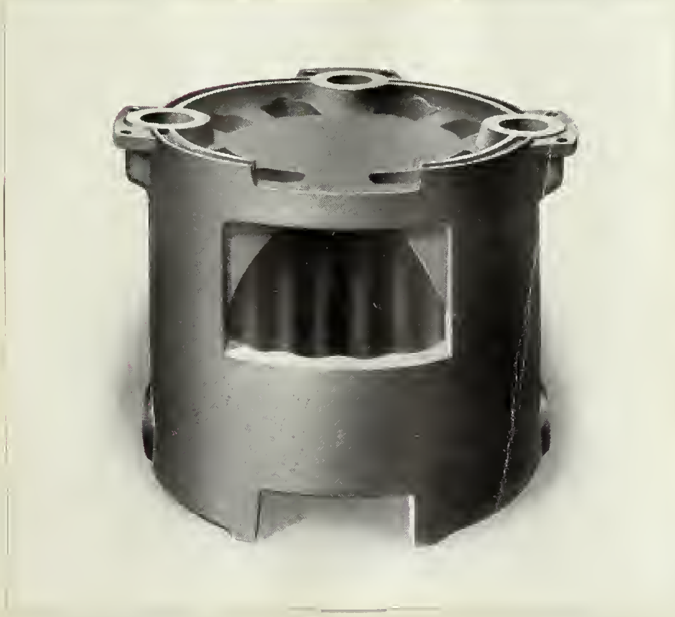

Figure 3.

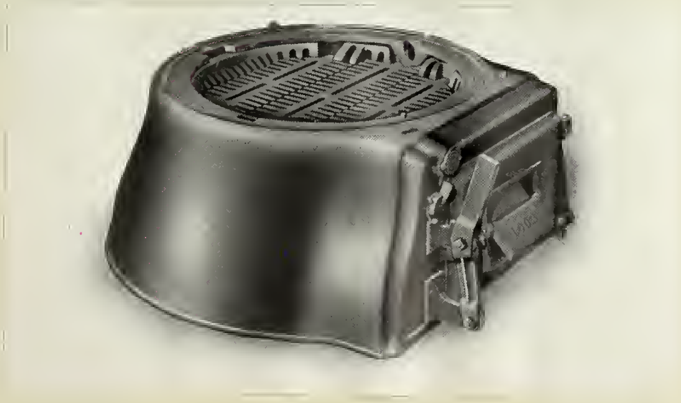

Figure 4.

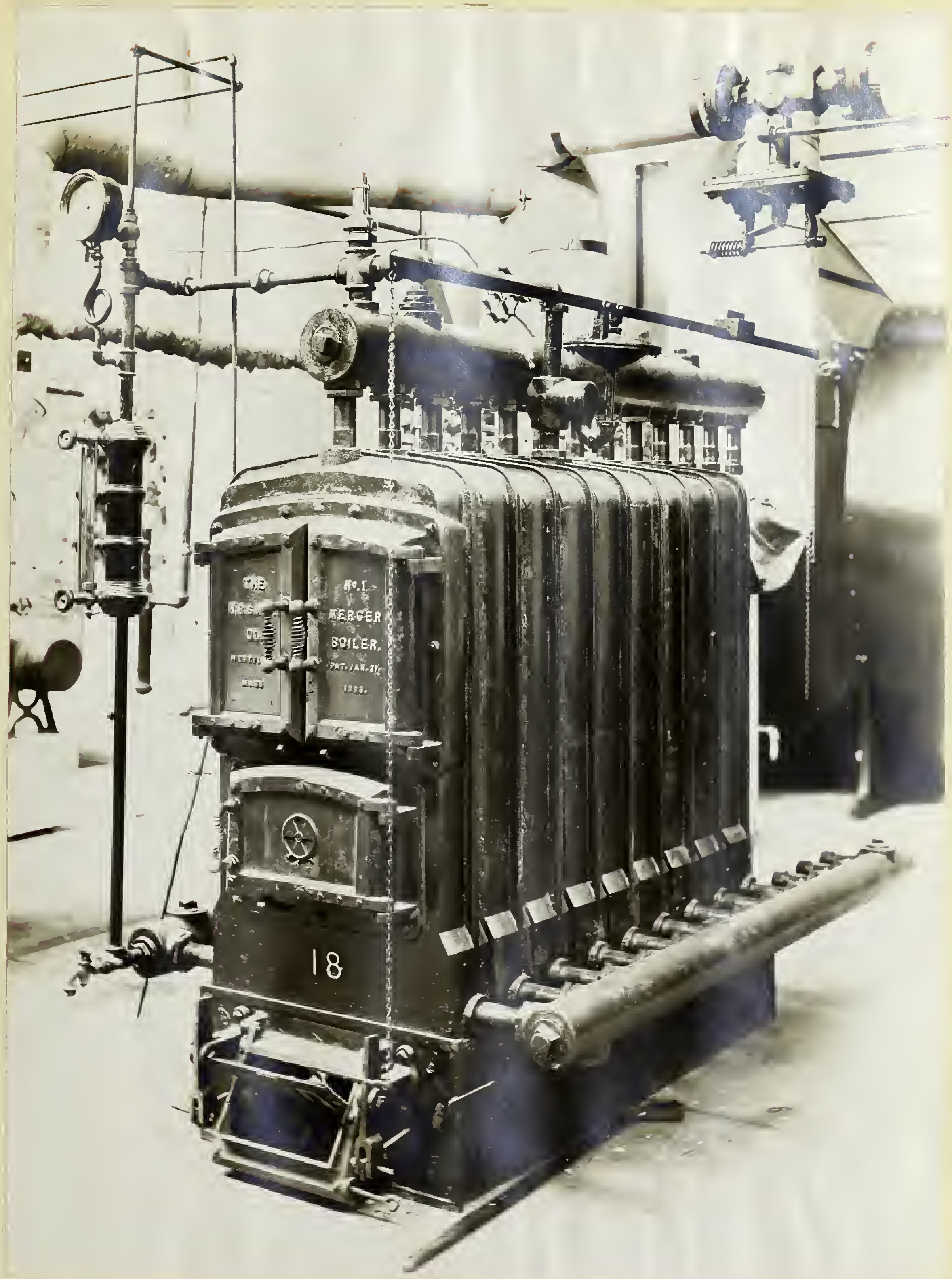
THE
CO.
No. 1
MERCER
BOILER.
PAT. JAN. 31
1888.
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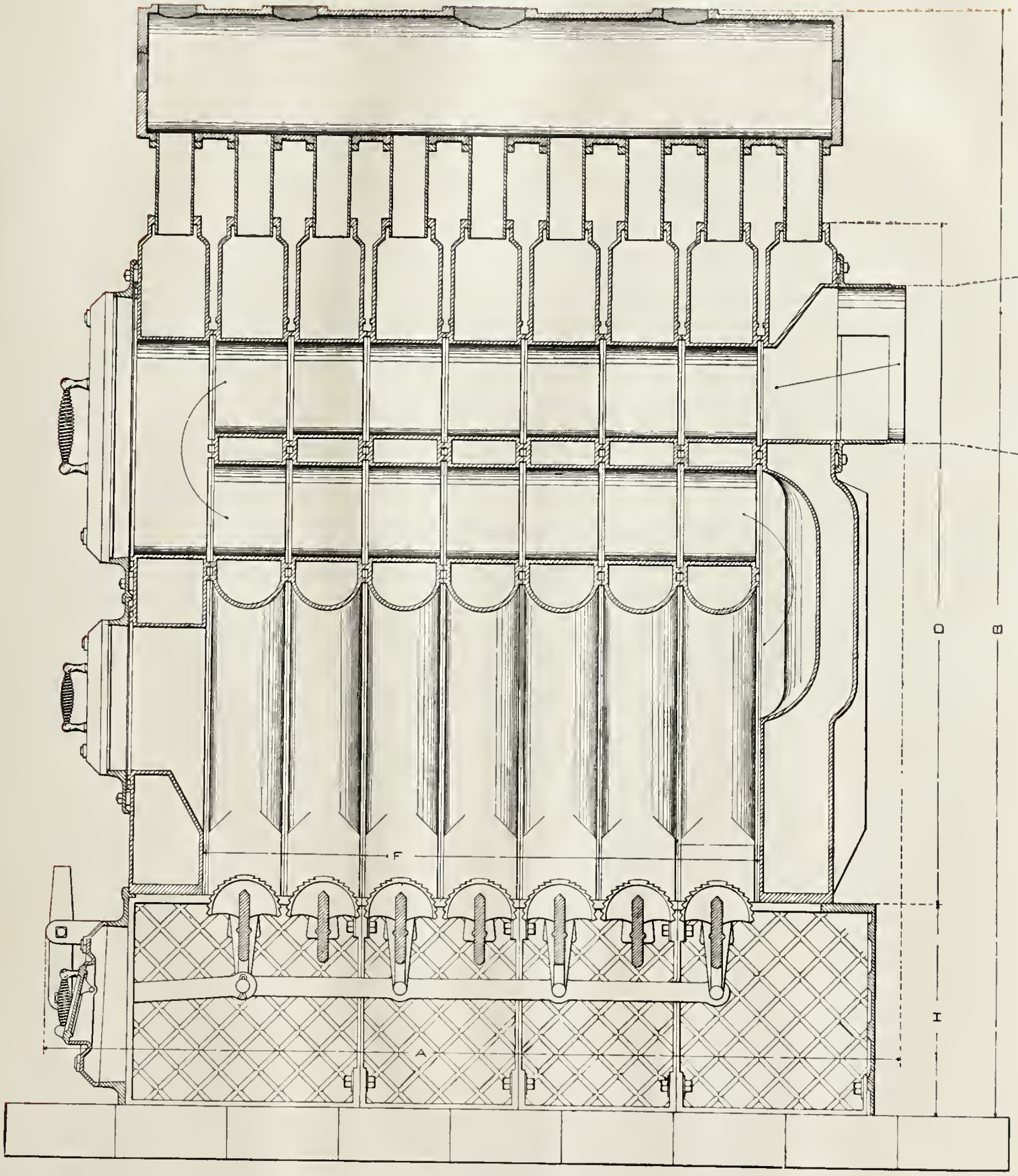
Figure 5.



Mercer Boiler

Figure 6.

fire contact surfaces and interior walls. Fig. 4 shows the base provided with the rocking and dumping grate.

The Mercer boiler which is of the sectional type, is made by the H. B. Smith Company of Westfield, Massachusetts, and is shown in Fig. 5. A longitudinal section of the boiler is shown in Fig. 6. The path of the hot gases is shown by the arrows. The grate is of the rocker type having alternate bars connected together and operated by levers on either side of the ash pit door. The circulation of the water is up thru the sections, out of the supply drums and back through the return drums at either side of the boiler.

The boilers are each provided with automatic regulators which close the front draft doors on the ash pit when the steam pressure exceeds a certain point.

CHIMNEYS:- Just back of each boiler and connected to it by a 10 inch breeching 11 feet long is a 14 inch galvanized iron stack 39 feet high.

FEED WATER:- The feed water used was the water of condensation from coils of the laboratory heating system. The feed water apparatus consists of a receiver for collecting the condensed water and two measuring tanks, one for each boiler.

Referring to Fig. 7, the method of obtaining water for the boiler is as follows:- The valve b being open the steaam pressure in the coils forces the condensed water through the valve a into the receiver. To fill either tank the valves k, g, i, b and a were closed and valves j, f, d, and c were opened. When the tank overflowed through j, the valves f, d, and c were closed and the valves b and a again opened.

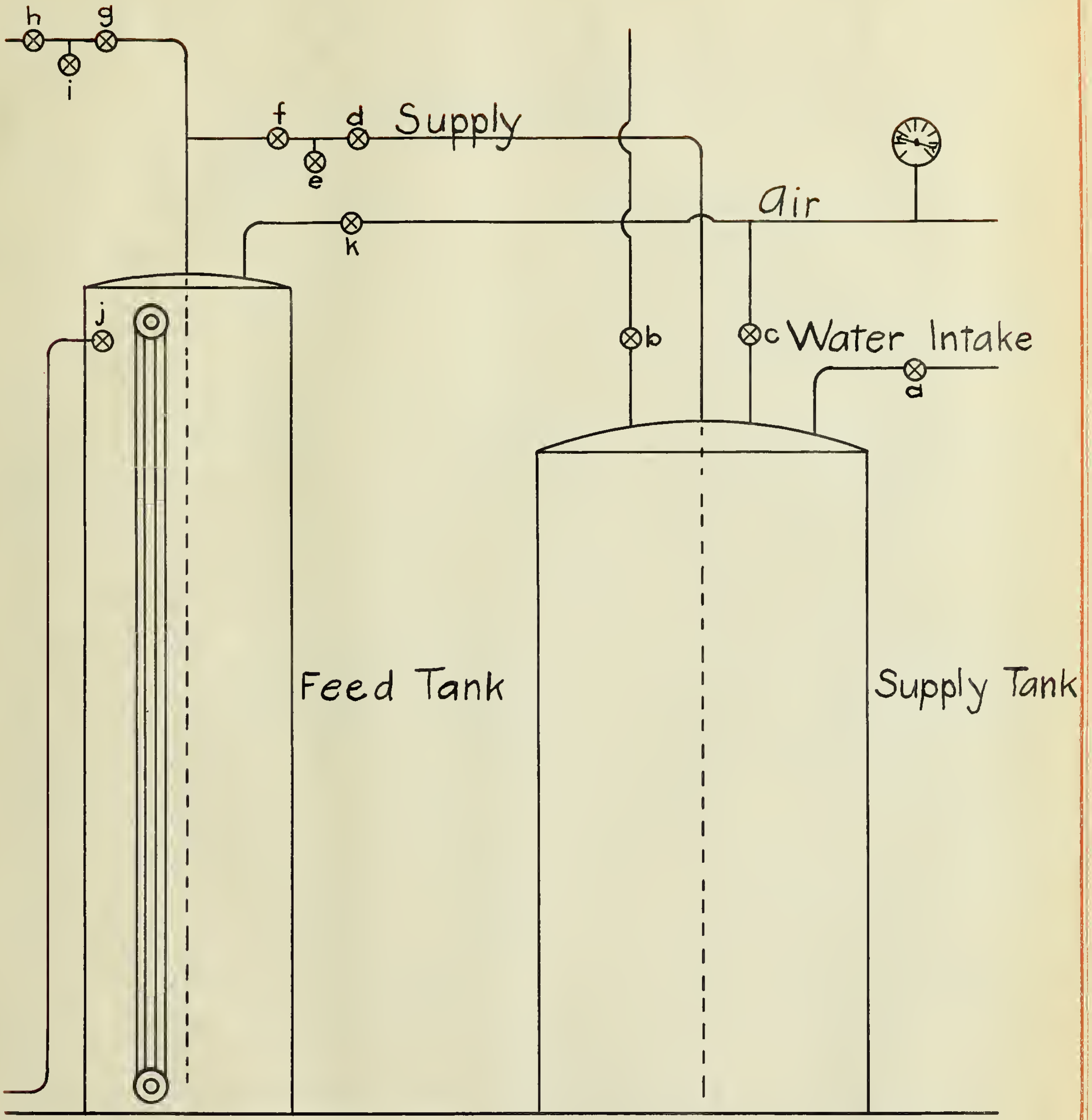

h
g
i
f
d
Supply
e
k
air
j
b
c
Water Intake
a
Feed Tank
Supply Tank

Figure 7.

After the water had stopped overflowing valve j was closed and k, g, and i opened. The amount of water fed to boiler was regulated by means of a needle valve-Fig. 1. The bleeder valves i and e were used to determine any leakage past the valves d, f, g and h.

REDUCING VALVE:- The pressure reducing valve shown at 1, Fig. 8, is made by the Foster Engineering Co., Newark, N.J. It is provided with a spring 2, for regulating the pressure in the separator.

SEPARATOR:- The separator shown in Fig. 8, consists of a 3 inch pipe 3, which leads from the boiler and extends down to the lower end of the 7 inch casing 4. The water is separated from the steam by the sudden reversal of the jet after passing down to the lower end of the 3 in. pipe. The separated water is collected in the graduated receiver 5. The dry steam passes up between the pipe 3 and casing 4, through the valve 8, through the orifice contained in the union 9, and into the exhaust. The steam may also be conducted through the by-pass 10, when it is not desirable to pass it through the orifice.

FLUE GAS APPARATUS:- The flue gases were analized with an Orsat Apparatus. It consists of a jacketed 100 cc. burette and a leveling bottle connected to the bottom of the burette by means of a capillary tube. Another Capillary tube connects the top of the burette to three pipettes and the open air.

The gas is analyzed by means of the absorption process. The first pipette which removes the carbon dioxide con-

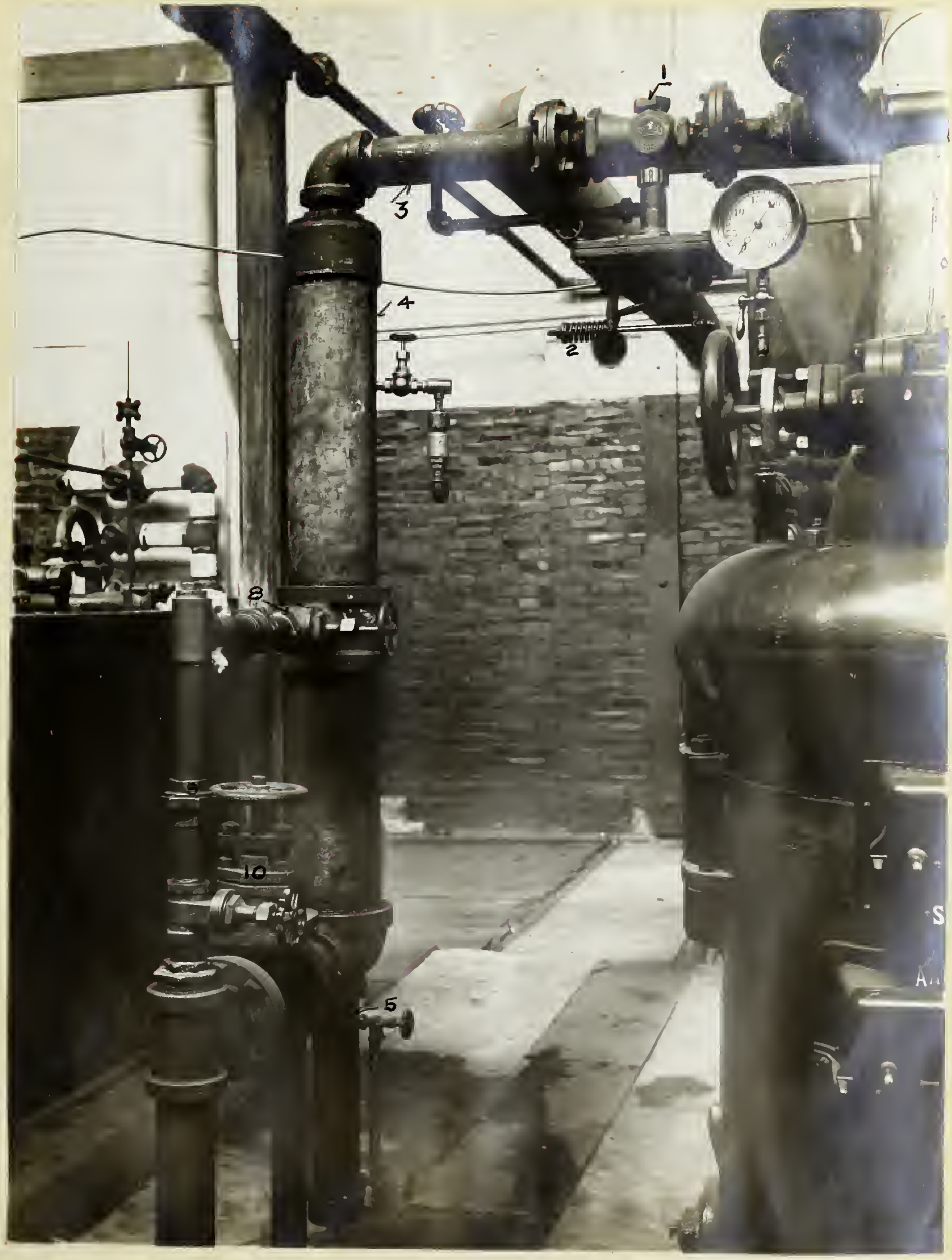


Figure 8.

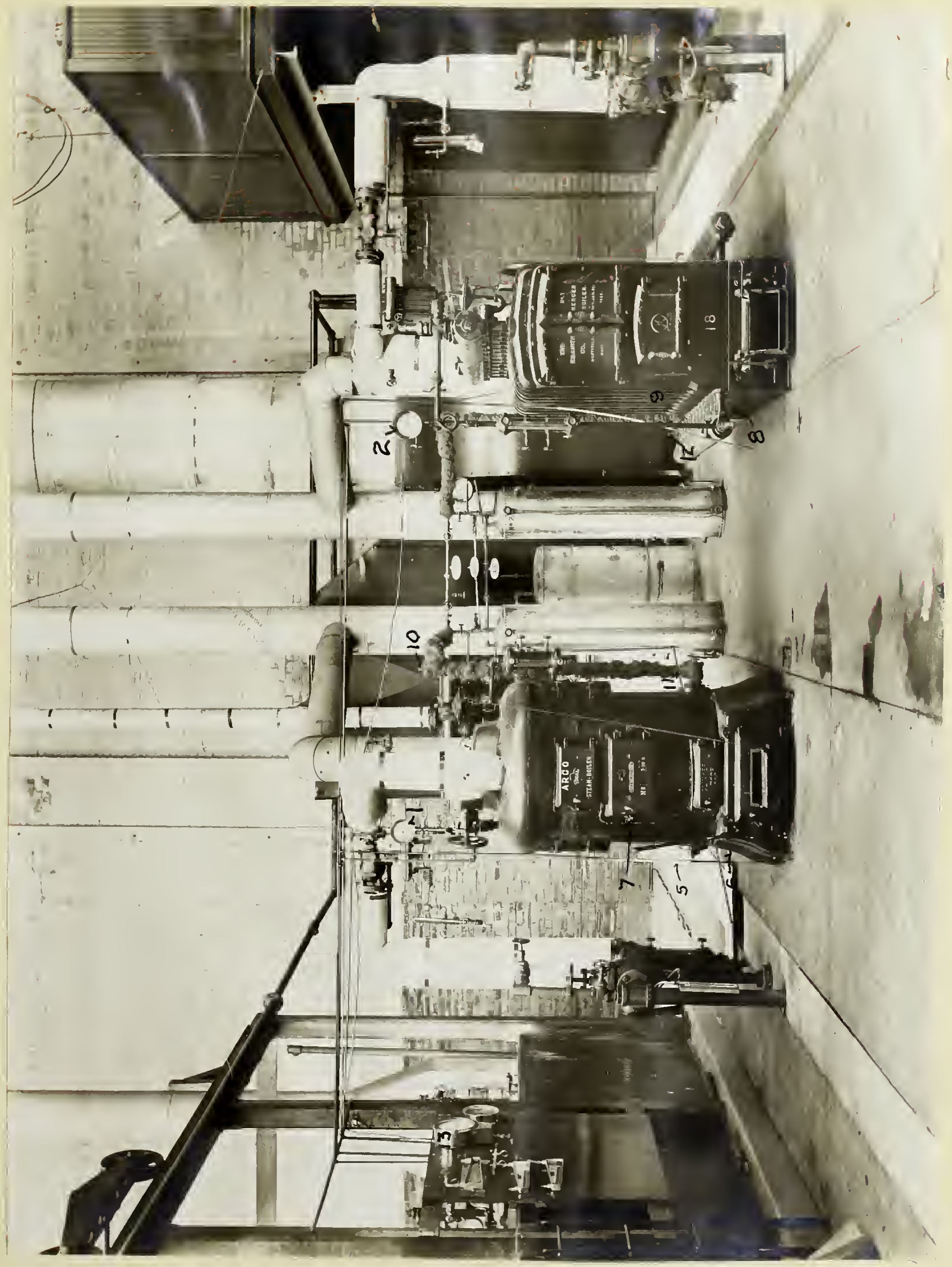
tains Potassium Hydroxide. After the Carbon dioxide has been removed, the gas is then passed into the second pipette containing Potassium Pyrogallate which takes up the oxygen. Finally the carbon monoxide is removed in the third pipette by means of Cuprous Chloride.

DRAFT GAGES:- The various drafts were taken by four differential draft gages, 1 , 2 , 3, and 4 . Fig. 1. Gages 1 and 2 measure the flue drafts, and are connected to the hoods of their respective boilers as shown in Fig. 9. The draft in the ash pit as well as that over the fire was measured by one draft gage for each boiler. This was obtained by inserting the tube 5 in the holes 6 and 7 for the Arco and in holes 8 and 9 for the Mercer.

THERMOMETERS:- The temperatures of the feed water entering the boiler was taken by mercury thermometers placed in the oil cups 10, 11 and 12 in the feed water pipes. The temperature of the feed water in the tanks to correct for difference in temperatures was obtained by mercury thermometer placed on the tanks.

A Bristol recording thermometer 13 Fig. 1, gave the temperature of the steam in the Mercer boiler and was used to observe the general condition of pressure during the test rather than a check on the pressure gage.

The flue gas temperatures were taken by two pyrometers graduated up to 1000° F. and inserted in the hoods between the boilers and back check damper.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13
ARCO
STEAM-BOILER
18

Figure 9

The temperature of the outside air was obtained from a Bristol recording thermometer.

An ordinary mercury thermometer gave the temperature of the boiler room.

PRESSURE GAGES:- The steam pressure in each boiler was taken by Bourdon steam gages 1 and 2, Fig. 9.

The difference between the separator and exhaust pressures was obtained by means of an U shaped manometer 14, Fig. 1, graduated in pounds per sq. in.

SCALES:- The scales for weighing the coal and ash were ordinary platform scales.

SAMPLE CANS:- Five galvanized iron cans were used for collecting the samples of coal ash and residual.

CALIBRATIONS.

The apparatus and instruments calibrated are as follows:-

BOILER:- The boilers had previously been calibrated and from this calibration curves were plotted as shown in Figs. 10 and 11.

FEED TANKS:- The feed tanks were calibrated at a temperature of 75°F. for increments of 1 lb. A graduated scale was placed on each tank so that the amount of water fed into the boiler could be read directly.

THERMOMETERS:- The mercury thermometers were calibrated by comparison with a standard thermometer and were found to be practically correct.

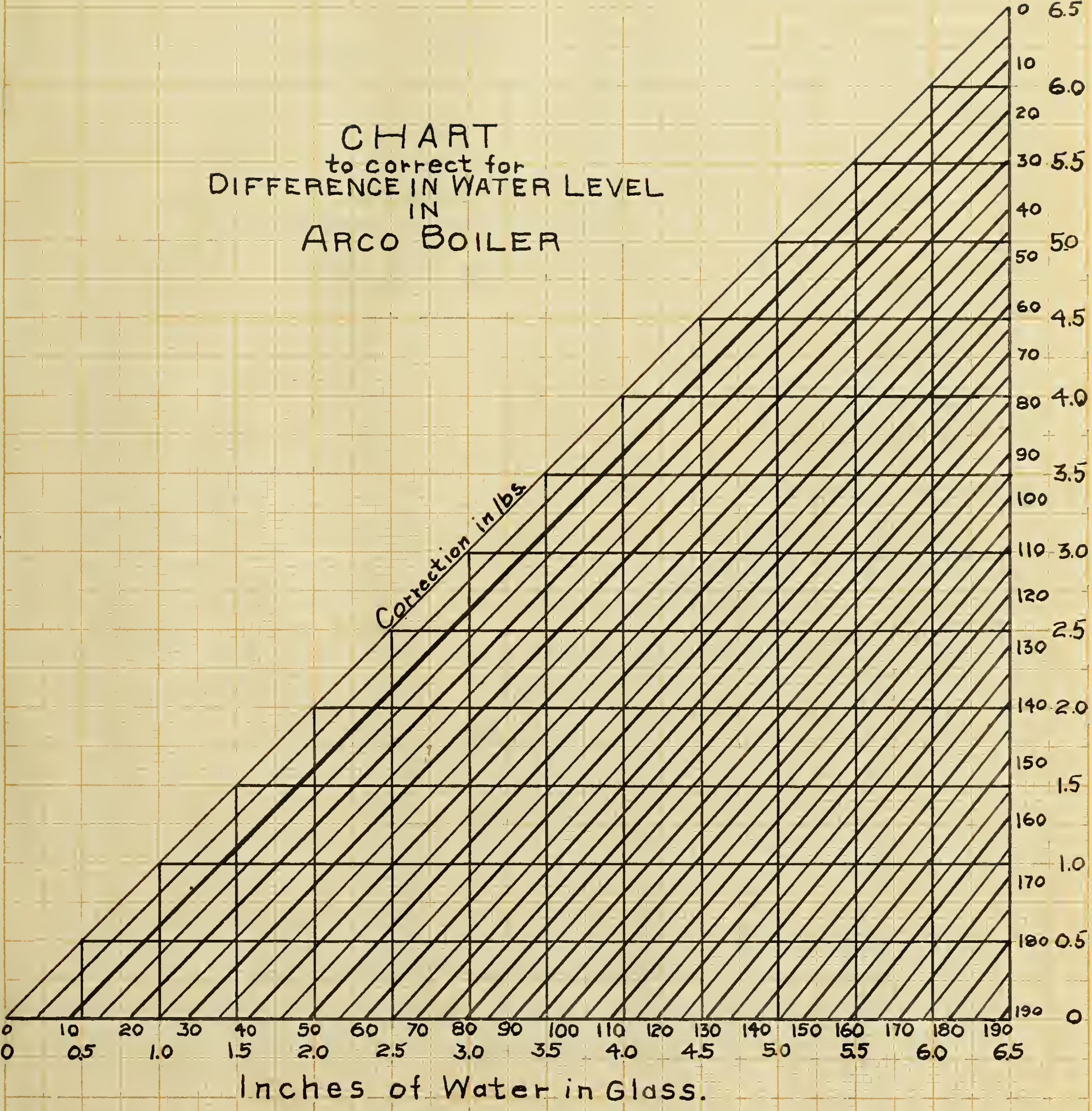

CHART
to correct for
DIFFERENCE IN WATER LEVEL
IN
ARCO BOILER

Fig. 10

F.T.

CHART
to correct for
DIFFERENCE IN WATER LEVEL
IN
MERCER BOILER

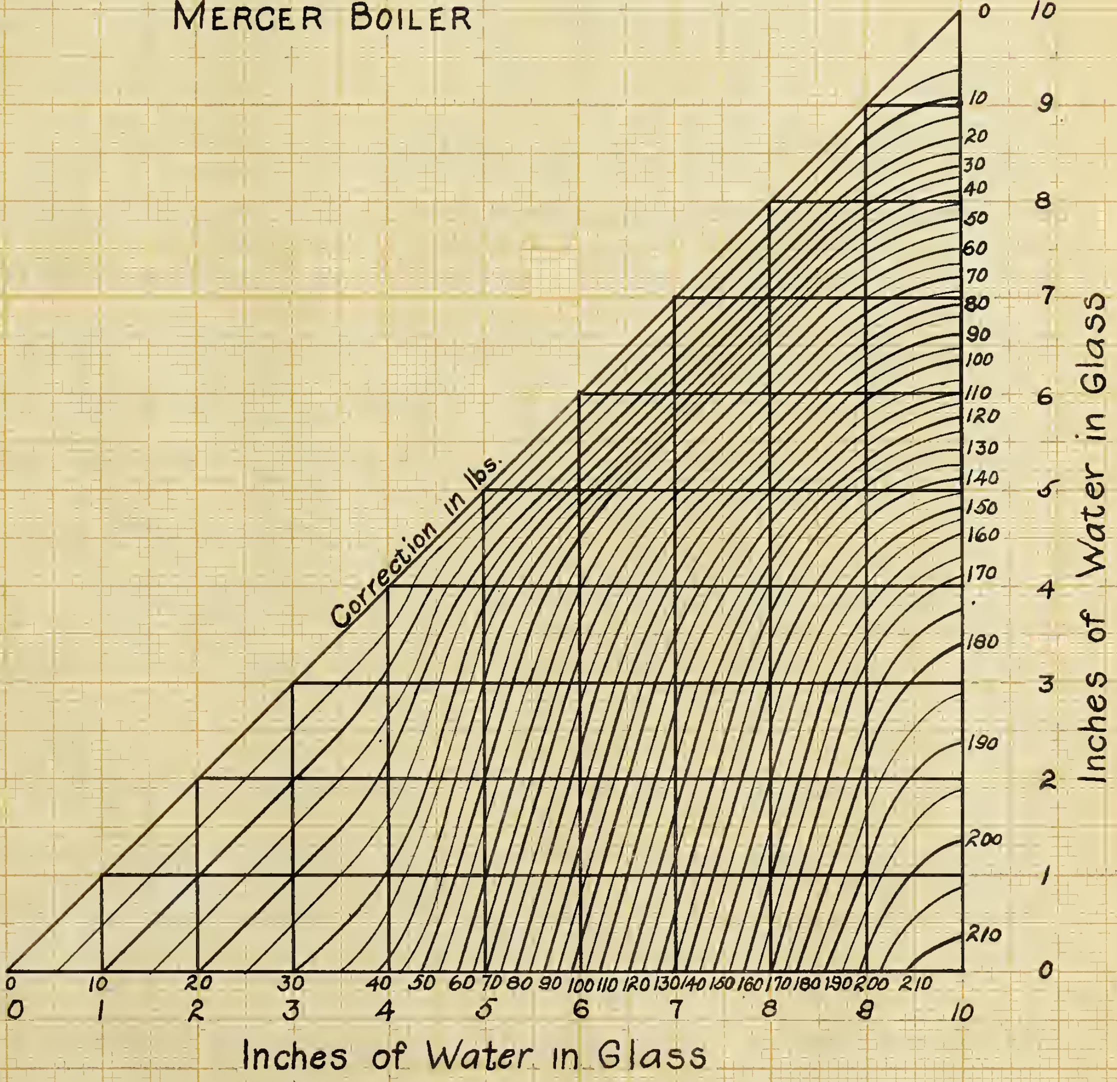

Fig.11.

The accuracy of the pyrometers was established by comparison with a standard.

PRESSURE GAGES:- The steam pressure gages were compared with a mercury column. Readings for increments of 1 lb. were taken and found to be sufficiently accurate.

SCALES:- The platform scales were calibrated by means of standard test weights.

MANNER OF CONDUCTING TEST.

METHOD OF STARTING AND STOPPING TESTS.

Each test was started and stopped by the standard method as adopted by the American Society of Mechanical Engineers. Steam being raised to the working pressure, all the fire was rapidly removed from the grate, the exhaust valve 15, Fig 1, closed to prevent the pressure from dropping, and the ash pit cleaned. As quickly as possible a new fire was started with a weighed quantity of wood and coal, the exhaust valve opened, and all the readings taken.

At the end of the test, after the fire had burned low the grates were cleaned and the ash removed from the pit and weighed. When the coal had been burned very low and the pressure failed to rise with the front draft doors wide open, the readings were taken, and all the fire was shaken from the grates. This residual was placed in a tight galvanized iron can and weighed.

METHOD OF FIRING:- Coal was fired in quantities of seventy-five pounds for the Arco and one-hundred and five pounds

for the Mercer boiler. These firings were made when the pressure began to drop with the front draft open, the automatic draft regulator keeping the pressure fairly constant at other times.

SAMPLING COAL AND ASH:- As each portion of coal was taken from the coal pile, a representative sample was put into one of the sampling cans and kept until the end of the test. The samples were then broken into small pieces and reduced by repeated quartering and crushing until a final sample of one kilogram was left. This was scattered out in a shallow pan, accurately weighed, and placed in an oven of boiler room temperature. About every twenty-four hours, this sample was weighed and when it stopped losing moisture, an average sample was enclosed in an air tight jar and sent to the Chemistry Department of the University of Illinois for analysis.

The ashes and residual were quartered and sampled in the same way but not subjected to the air drying process. Samples of these were also bottled up for analysis.

MEASUREMENT OF WATER:- The weight of water fed to the boilers was determined by reading the weight on the feed tank scales and correcting for difference of temperature.

PRESSURES:- The pressure in the separator was kept as nearly two pounds as possible by adjusting the reducing valve. This pressure was the one used in the calculations.

QUALITY OF STEAM:- The moisture in the steam was determined from the water collected in the graduated receiver 5, Fig. 8. When the water neared the top of the scale, the height

was read, time recorded, and the water run out until it stood opposite the zero mark.

THE GAS TEMPERATURES:- It was found necessary in the case of the Arco boiler to remove the pyrometer immediately after firing, owing to the flue gas temperature rising above the limit (1000°) of the thermometer.

DURATION OF TESTS:- The first test on each boiler lasted about nine or ten hours, the second test fifteen or sixteen hours, and the last test about twenty-four hours. The exact time of stopping was governed by the condition of the fire.

READINGS:- Every twenty minutes the following observations were taken:-

Boiler pressure,
Separator pressure,
Draft in flue,
Draft over fire,
Draft in ash pit,
Temperatures of enternal air,
Temperatures of boiler room,
Temperatures of feed water entering boiler,
Temperatures of gases escaping from boiler,
Height of water in feed tank,
Height of water in receiver,
Height of water in boiler.

The weight of coal when fired, and the time of poking, shaking and raking the fire was recorded.

LOG SHEET.

	ITEMS.			
	File No.,	164	168	170
	Date of test,	2-29-08	3-6-'08	3-9-'08
1.	Duration of test, hours,	9.73	15.47	24.05
	BOILER.			
2.	Number and description, Ideal Arco. 1-28-S.			
3.	Builder's rating, sq. ft. radiation,	800	800	800
4.	Grate, diameter 28", area, sq.ft..	4.28	4.28	4.28
5.	Fuel capacity to center of fire door, lbs.	290	290	290
5.1	Available fuel capacity, lbs.	232	232	232
6.	Heating surface, direct, 18.8 sq. ft.; Flue, sq. ft.	20.7	20.7	20.7
	Total, sq. ft.	39.5	39.5	39.5
7.	Ratio of direct to total water heating surface, per cent,	43	43	43
8.	Ratio of water heating surface to grate surface, 1 to	10.2	10.2	10.2
	CHIMNEY.			
9.	Round chimney flue, 14 in. diam. feet high,	39	39	39
	AVERAGE PRESSURES.			
10.	Steam pressure in boiler by gage, lbs. per sq. in.	5.51	6.07	5.96
11.	Steam pressure receiver by gage, lbs. per sq. in.	1.85	1.96	1.92
12.	Force of draft in flue, ins. of water.	.133	.171	.137
13.	Force of draft over fire, ins. of water.	.086	.092	.108
13.1	Force of draft in ash pit, ins. of water.	.055	.049	.049
	AVERAGE TEMPERATURES.			
14.	Of external air, degs. Fahr.	35.7	36.4	39.4
15.	Of boiler room, degs. Fahr.	69.4	78.1	78.7
16.	Of feed water entering boiler, degs. Fahr.	165.2	172.2	176.4
17.	Of gases escaping from boiler, degs. Fahr.	595	645	591

FUEL.

18.	Kind of fuel, Anthracite Wyoming District Pottsville, Pa.			
19.	Size, Egg.			
20.	Weight of wood used in lighting fire, lbs.	25	25	25
21.	Weight of fuel as fired, lbs.	300	450	600
21.1	Weight of fuel as fired + fuel equivalent of wood, lbs.	310	460	610
21.2	Weight of fuel as fired + fuel equivalent of wood - moist fuel equivalent of residual fuel, lbs	243	381	543
22.	Percentage of moisture in fuel as fired, per cent.	5.48	4.34	4.20
23.	Total dry fuel fired, lbs.	293	440	584
23.1	Total dry fuel fired- dry fuel equivalent to carbon in residual fuel, lbs.	229	364	519
23.2	Total dry fuel fired-dry fuel equivalent to the carbon in the "ash and refuse" and of the carbon in the residual fuel, lbs.	222	358	504
24.	Total ash and refuse (from ash pit) lbs.	13.5	11.5	38
25.	Residual fuel (removed at close of test) lbs.	83	106	91

PROXIMATE ANALYSIS OF FUEL.

26.	Fixed Carbon, per cent,as sampled.	77.03	77.96	78.08
27.	Volatile matter, per cent.as spld.	6.71	6.79	6.80
28.	Moisture, per cent. as sampled.	5.48	4.34	4.20
29.	Ash, per cent. as sampled.	10.78	10.91	10.92
		100.00	100.00	100.00

ANALYSIS OF RESIDUAL FUEL.

37.	Carbon, per cent.	68.95	64.66	64.11
38.	Earthy matter, per cent.	30.75	35.10	35.72
39.	Moisture, per cent.	.30	.24	.17
		100.00	100.00	100.00

ANALYSIS OF ASH AND REFUSE.

40.	Carbon, per cent.	45.27	44.93	34.52
41.	Earthy matter, per cent.	54.45	54.69	65.36
42.	Moisture, per cent.	.28	.38	.12
		100.00	100.00	100.00

FUEL PER HOUR.

43.	Dry fuel fired per hour, lbs.	23.5	23.5	21.6
44.	Dry fuel fired per sq. ft. of grate surface per hour, lbs.	5.5	5.5	5.0

CALORIFIC VALUE OF FUEL.

45.	Calorific value of fuel by oxygen calorimeter per lb. of dry fuel, B.T.U.	13090	13090	13090
46.	Calorific value of fuel by oxygen calorimeter per lb. of fuel as fired, B.T.U.	12514	12665	12658

QUALITY OF STEAM.

47.	Moisture in steam, per cent.	0.988	1.11	0.983
48.	Factor for correction for quality,	.9906	.9894	.9906

WATER.

49.	Total water fed to boiler, lbs.	1449	2393	3690
50.	Water actually evaporated corrected for quality of steam. lb.	1435	2367	3655
51.	Factor of evaporation.	1.051	1.044	1.040
52.	Equivalent water evaporated into dry steam from and at 212 degrees Fahr. lbs.	1509	2471	3800

WATER PER HOUR.

53.	Equivalent evaporation per hour from and at 212 degrees Fahr. lbs.	155	160	158
53.1	Equivalent horse power per hour.	4.49	4.63	4.58
54.	Equivalent evaporation per hour from and at 212 degs. Fahr. per sq. ft. of water heating surface. lbs.	3.92	4.05	4.00
55.	Mean load carried during test (Steam condensed per sq. ft. of radiating surface per hour taken at 0.3 lb). Sq. ft. of radiating surface.	517	532	527
55.1	Load carried including external radiating surface of boiler. sq. ft. of radiating surface.	554	570	565
56.	Percentage of builder's rating developed, per cent.	64.7	66.5	65.8

ECONOMIC RESULTS.

57.	Equivalent evaporation from and at 212 degs. Fahr. per lb. of fuel as fired, lbs.	6.20	6.48	7.00
58.	Equivalent evaporation from and at 212 degs. Fahr. per lb. of dry fuel, lbs.	7.10	6.90	7.53
59.	Fuel fired per hour per 100 sq. ft. of radiating surface, lbs.	4.84	4.62	4.30
60.	Dry fuel fired per hour per 100 sq. ft. of radiating surface, lbs.	4.56	4.42	4.10

EFFICIENCY.

61.	Efficiency of boiler and furnace; heat absorbed by the boiler per lb. of dry consumed fuel ÷ heating value of 1 lb. of dry fuel. per cent.	52.3	50.8	55.6
62.	Efficiency of plant; heat absorbed by the boiler per lb. of fuel as fired ÷ heating value of 1 lb. of fuel as fired. percent.	47.8	49.4	53.3

COST OF EVAPORATION.

63.	Cost of fuel per ton of 2000 lbs. delivered to boiler room,	$8.25	$8.25	$8.25
64.	Cost of fuel per 100 sq. ft. of radiating surface per hour, cts.	2.00	1.90	1.80
65	Cost of evaporating 1000 lb. of water from and at 212 degs. Fahr. cents.	66.6	63.7	59.1

METHOD OF FIRING.

68.	Kind of firing. Spreading.			
70.	Average weight of fuel fired at each firing. lbs.	75	75	75
71.	Average interval between firing, hours.	2.17	2.517	2.98
72.	Average interval between times of shaking or breaking up fire. hours.	7.82	10.275	4.15
73.	Carried 2 lb. pressure without attention; (Max. period) hrs.	2.33	3.33	7.00

FLUE GAS ANALYSIS.

74.	Carbon dioxide (CO_2) per cent.	4.25	4.33	3.84
75.	Oxygen (O), per cent.	15.4	14.10	14.62
76.	Carbon Monoxide (CO), per cent.	1.4	2.20	3.46

LOG SHEET.

	ITEMS.			
	File No.	165	169	171
	Date of test,	2-29-08	3-6-'08 3-7-'08	3-6-'08 3-10-'08
1.	Duration of trial, hours.	10.42	16.78	23.57
	BOILER.			
2.	Number and description. Mercer Sectional.	#1-918	#1-918	$1-918
3.	Builder's rating, sq. ft. radiation.	1075	1075	1075
4.	Grate, diameter or dimensions. 18" x 48", area sq. ft.	6	6	6
5.	Fuel capacity to center of fuel door. lbs.	370	370	370
5.1	Available fuel capacity, lbs.	296	296	296
6.	Heating surface; direct 21.89 sq. ft. Flue, sq. ft.	53.98	53.98	53.98
	Total, sq. ft.	75.87	75.87	75.87
7.	Ratio of direct to total water heating surface, per cent.	28.9	28.9	28.9
8.	Ratio of water heating surface to grate surface, 12.6 to 1.			
	CHIMNEY.			
9.	Round chimney flue. 14 in. diam. heighth.	39	39	39
	AVERAGE PRESSURES.			
10.	Steam pressure in boiler by gage, lbs. per sq. in.	4.05	5.24	5.13
11.	Steam pressure receiver by gage, lbs. per sq. in.	1.75	1.97	1.88
12.	Force of draft in flue. ins. water,	.143	.136	.127
13.	Force of draft over fire, ins. of water.	.051	.054	.057
13.1	Force of draft in ash pit, ins. of water.	.020	.026	.014
	AVERAGE TEMPERATURES.			
14.	Of external air, degs. Fahr.	35.7	36.4	39.4
15.	Of boiler room, degs. Fahr.	69.4	78.1	78.7
16.	Of feed water entering boiler, degs. Fahr.	164.6	166.9	172.8

17.	Of gases escaping from boiler, degs Fahr.	590	557	573

FUEL.

18.	Kind of fuel, Anthracite Wyoming District, Pottsville, Pa.			
19.	Size, Egg.			
20.	Weight of wood used in lighting fire, lbs.	30	30	30
21.	Weight of fuel as fired, lbs.	420	525	735
21.1	Weight of fuel as fired + fuel equivalent of wood, lbs.	432	537	747
21.2	Weight of fuel as fired + fuel equivalent of wood - moist fuel equivalent of residual fuel, lbs.	296	441	625
22.	Percentage of moisture in fuel as fired, per cent.	5.48	4.34	4.20
23.	Total dry fuel fired, lbs.	408	514	716
23.1	Total dry fuel fired - dry fuel equivalent to carbon in residual fuel, lbs.	278	421	599
23.2	Total dry fuel fired - dry fuel equivalent to the carbon in the "ash and refuse" and of the carbon in the residual fuel, lbs.	274	408	564
24.	Total ash and refuse (from ash pit) lbs.	6	21	44
25.	Residual fuel (removed at close of test) lbs.	159	130	160

PROXIMATE ANALYSIS OF FUEL.

26.	Fixed Carbon, per cent as sampled.	77.03	77.96	78.08
27.	Volatile matter, " " " "	6.71	6.79	6.80
28.	Moisture, " " " "	5.48	4.34	4.20
29.	Ash, " " " "	10.78	10.91	10.92
		100.00	100.00	100.00

ANALYSIS OF RESIDUAL FUEL.

37.	Carbon, per cent.	73.50	63.97	65.82
38.	Earthy matter, per cent.	26.06	35.73	33.74
39.	Moisture, per cent.	.44	.34	.44
		100.00	100.00	100.00

ANALYSIS OF ASH AND REFUSE.

40.	Carbon, per cent.	62.83	55.27	40.65
41.	Earthy matter, per cent.	36.48	44.07	58.93
42.	Moisture, per cent.	.69	.66	.42
		100.00	100.00	100.00

FUEL PER HOUR.

43.	Dry fuel fired per hour, lbs.	26.7	25.1	25.4
44.	Dry fuel fired per sq. ft. of grate surface per hour, lbs.	4.4	4.2	4.2

CALORIFIC VALUE OF FUEL.

45.	Calorific value of fuel by oxygen calormimete per lb. of dry fuel, B. T. U.	13090	13090	13090
46.	Calorific value of fuel by oxygen calorimeter per lb. of fuel as fired, B. T. U.	12514	12665	12658

QUALITY OF STEAM.

47.	Moisture in steam, per cent.	0.84	0.71	0.73
48.	Factor for correction for quality,	.9920	.9933	.993

WATER.

49.	Total water fed to boiler, lbs.	1906	3218	4585
50.	Water actually evaporated, corrected for quality of steam. lbs.	1890	3196	4553
51.	Factor of evaporation,	1.051	1.049	1.043
52.	Equivalent water evaporated into dry steam from and at 212 degrees Fahr. lbs.	1987	3353	4749

WATER PER HOUR.

53.	Equivalent evaporation per hour from and at 212 degrees Fahr. lbs.	190	200	202
54.	Equivalent evaporation per hour from and at 212 degs. Fahr. per sq. ft. of water heating surface, lbs.	2.66	2.63	2.66
55.	Mean load carried during test (steam condensed per sq. ft. of radiating surface per hour taken at 0.3 lb.) sq. ft of radiating surface.	632	666	671
55.1	Load carried including external radiating surface of boiler, Sq. ft. of radiating surface.	755	769	874
56.	Percentage of builder's rating developed. per cent.	58.8	61.9	62.7

ECONOMIC RESULTS.

57.	Equivalent evaporation from and at 212 degs. Fahr. per lb. of fuel as fired, lbs.	6.71	7.60	7.60
58.	Equivalent evaporation from and at 212 degs. Fahr. per lb. of dry fuel, lbs.	7.25	8.20	8.43
59.	Fuel fired per hour per 100 sq. ft. of radiating surface, lbs.	4.49	3.95	3.95
60.	Dry fuel fired per hour per 100 sq. ft. of radiating surface. lbs.	4.21	3.77	3.79

EFFICIENCY.

61.	Efficiency of boiler and furnace; heat absorbed by the boiler per lb. of dry consumed fuel ÷ heating value of 1 lb. of dry fuel. per cent.	53.1	60.5	64.1
62.	Efficiency of plant; heat absorbed by the boiler per lb. of fuel as fired ÷ heating value of 1 lb. of fuel as fired. per cent.	51.7	58.0	60.1

COST OF EVAPORATION.

63.	Cost of fuel per ton of 2000 lbs. delivered to the boiler room.	$8.25	$8.25	$8.25
64.	Cost of fuel per 100 sq. ft. of radiating surface per hour.cts.	1.9	1.6	1.6
65.	Cost of evaporating 1000 lb. of water from and at 212 degs Fahr. cents.	61.5	54.3	54.2

METHOD OF FIRING.

68.	Kind of firing, Spreading.			
70.	Average weight of fuel fired at each firing, lbs.	105	105	105
71.	Average interval between firing, hours.	3.47	4.19	3.93
73.	Carried 2 lb. pressure with attention (Max. period) hrs.	2.0	7.67	4.33

FLUE GAS ANALYSIS.

74.	Carbon dioxide (CO_2) per cent.	6.50	7.82	7.87
75.	Oxygen (O) per;cent.	13.9	11.4	11.5
76.	Carbon monoxide (CO) per cent.	.5	.5	.3

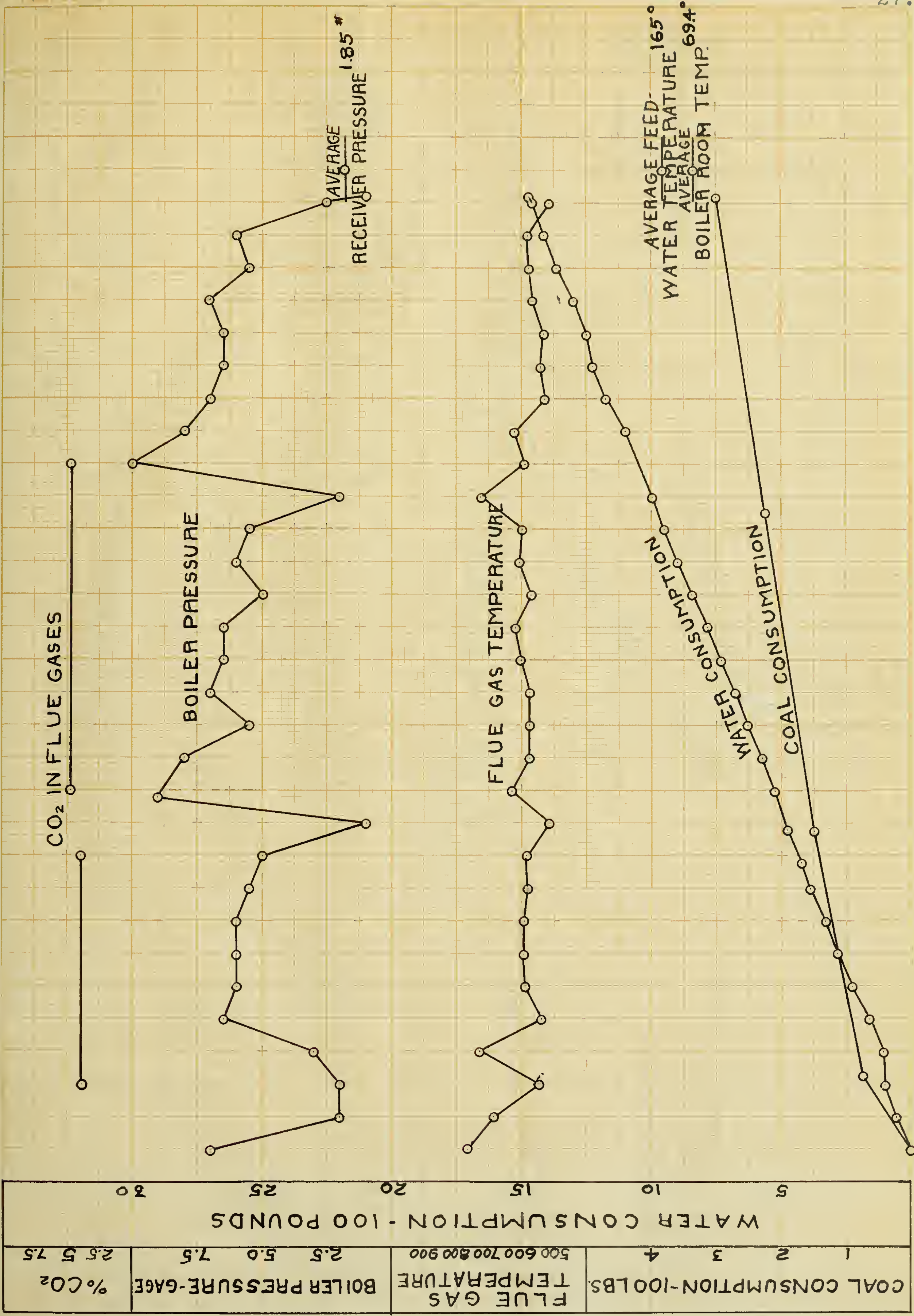

FIG 12 LOG OF FILE NO. 164.

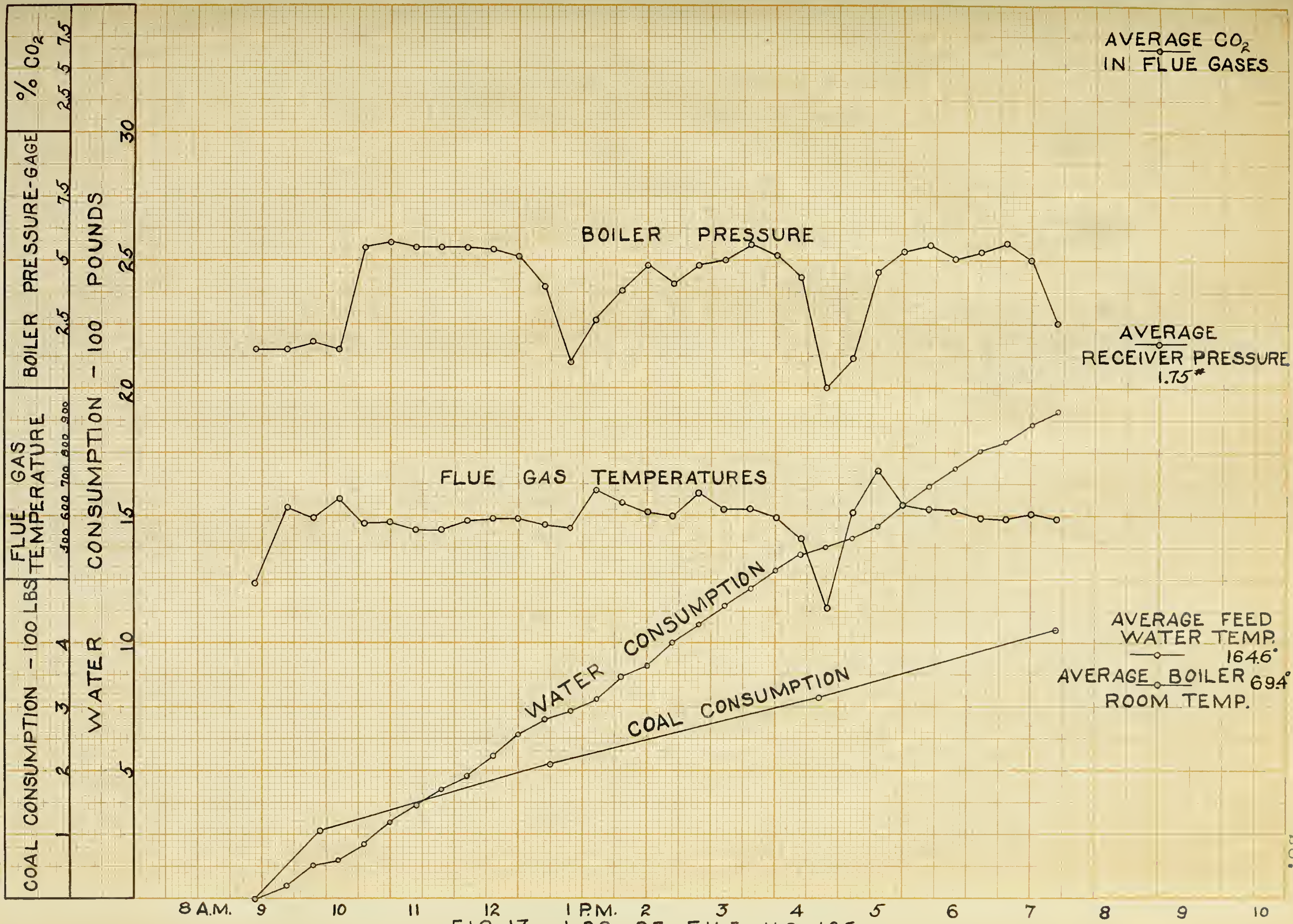

FIG. 13 - LOG OF FILE NO 165

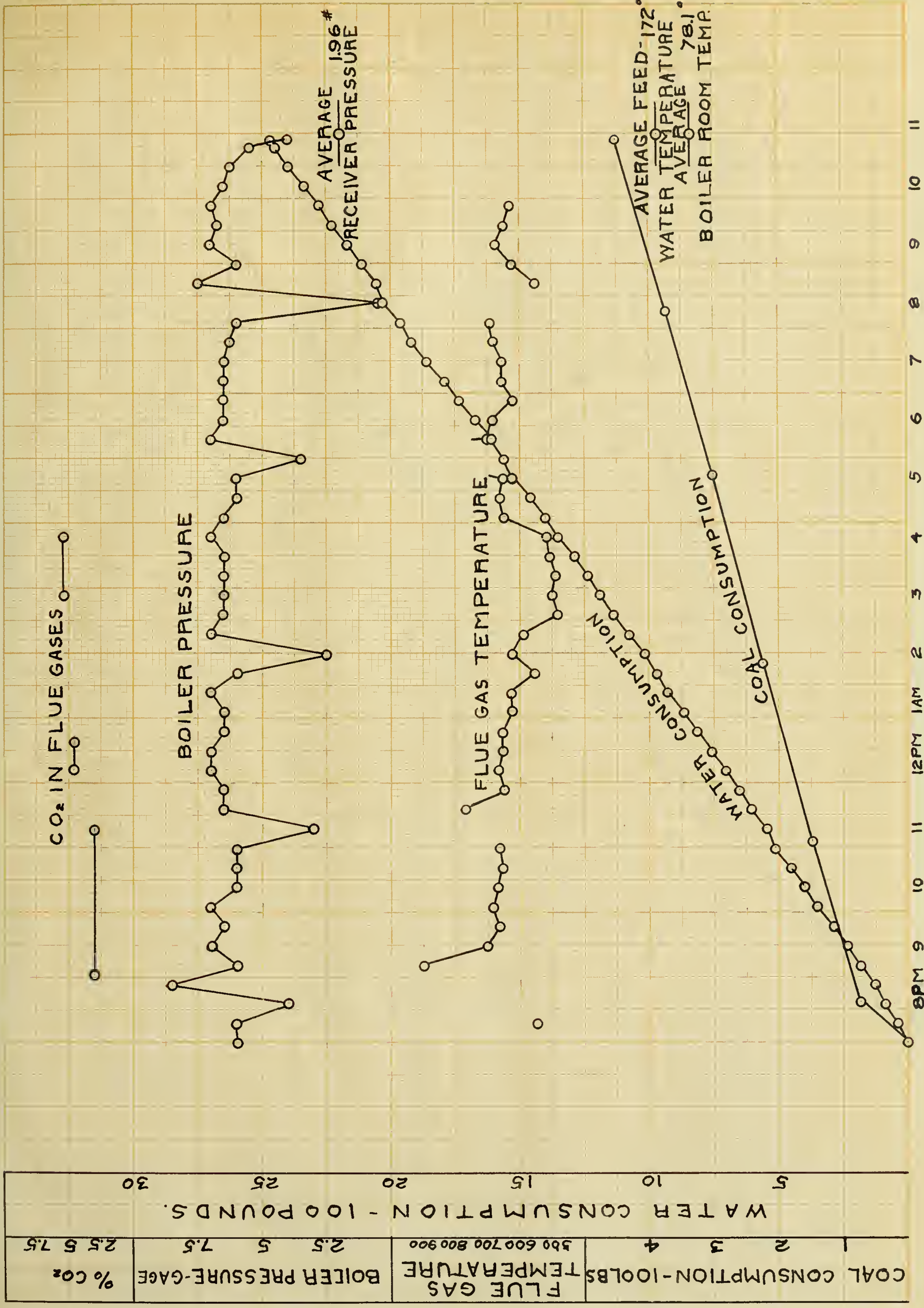

FIG.14-LOG OF FILE NO.168.

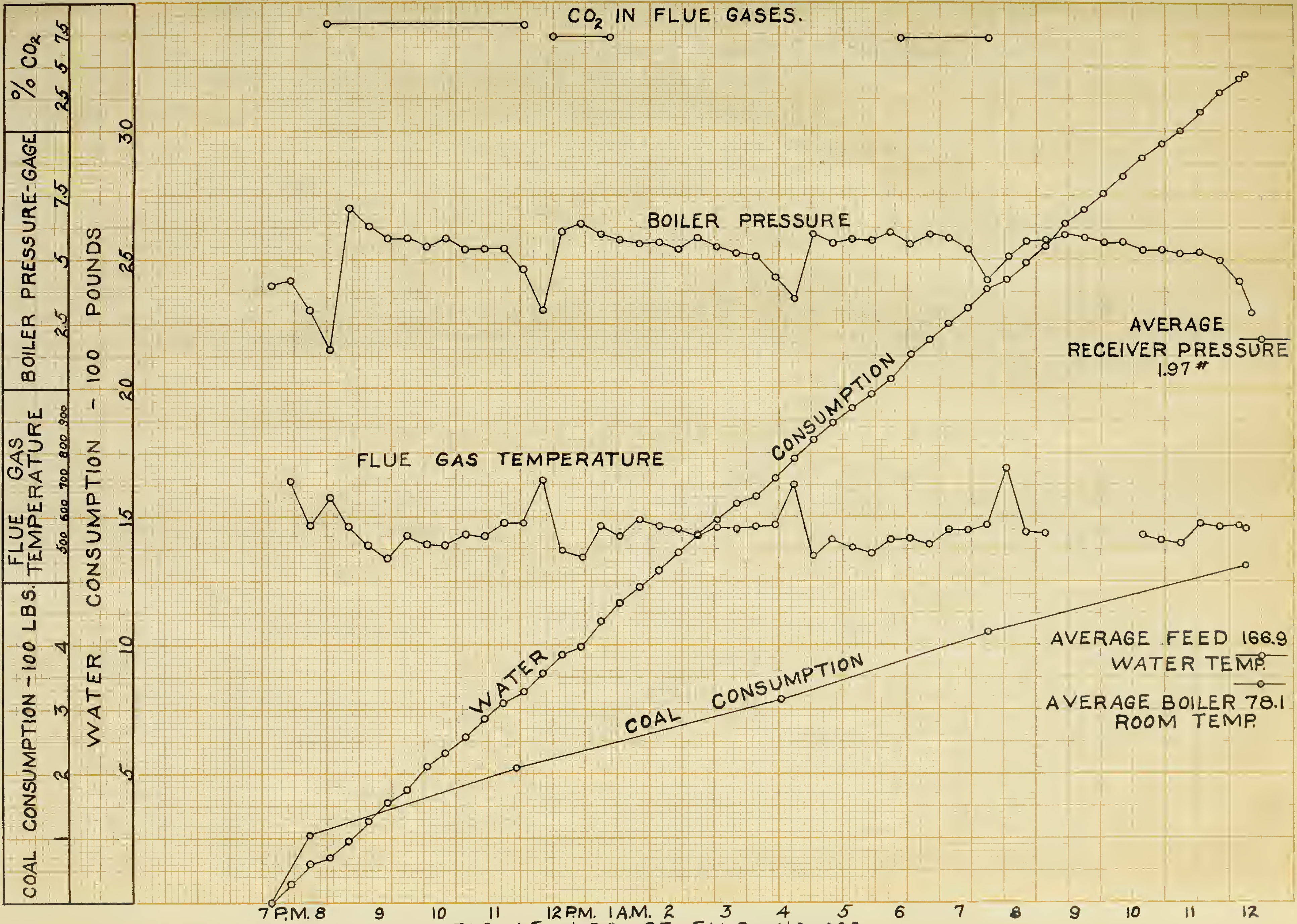

FIG. 15 - LOG OF FILE NO 169.

U. OF I. S. S. FORM

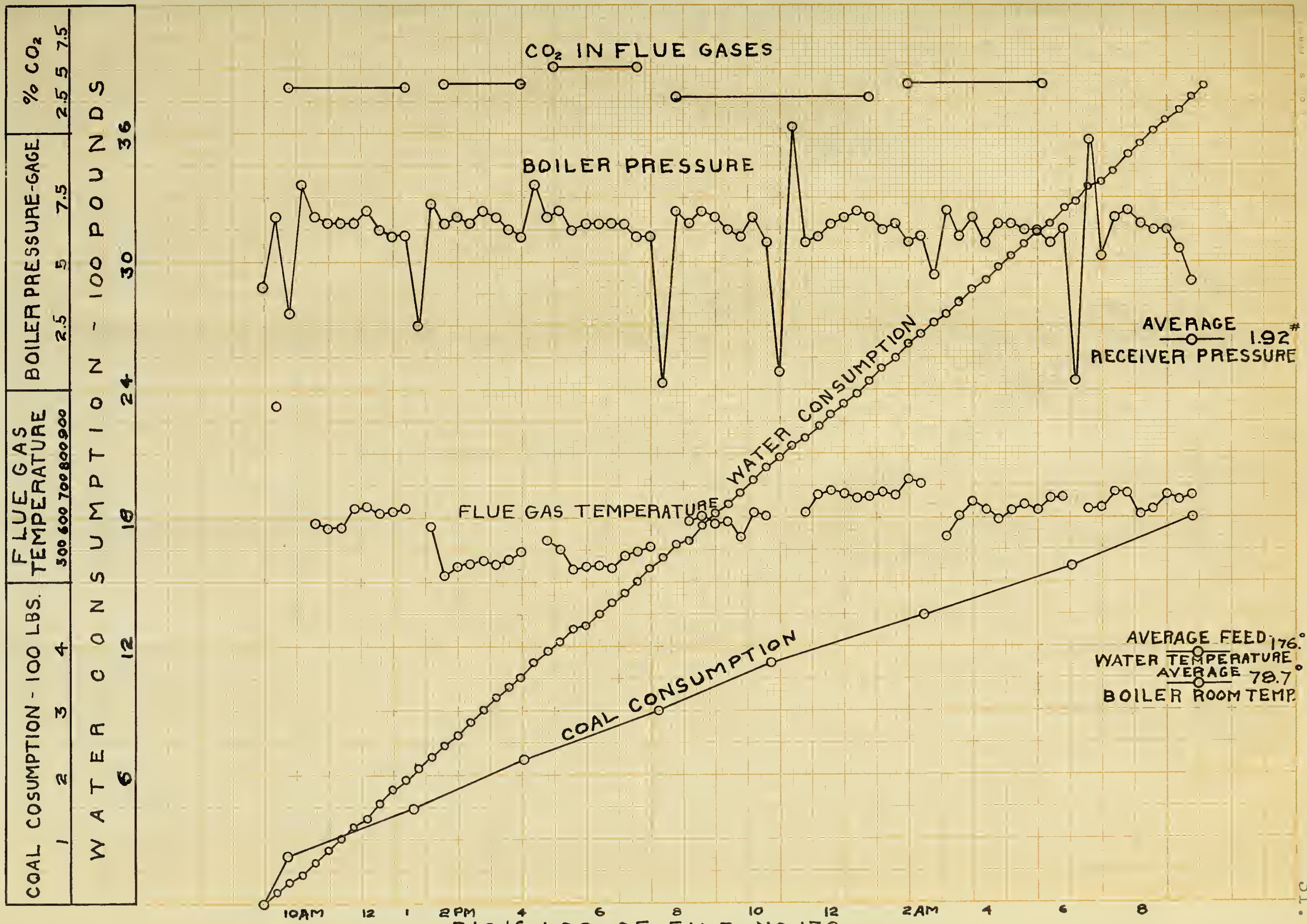

FIG.16-LOG OF FILE NO. 170.

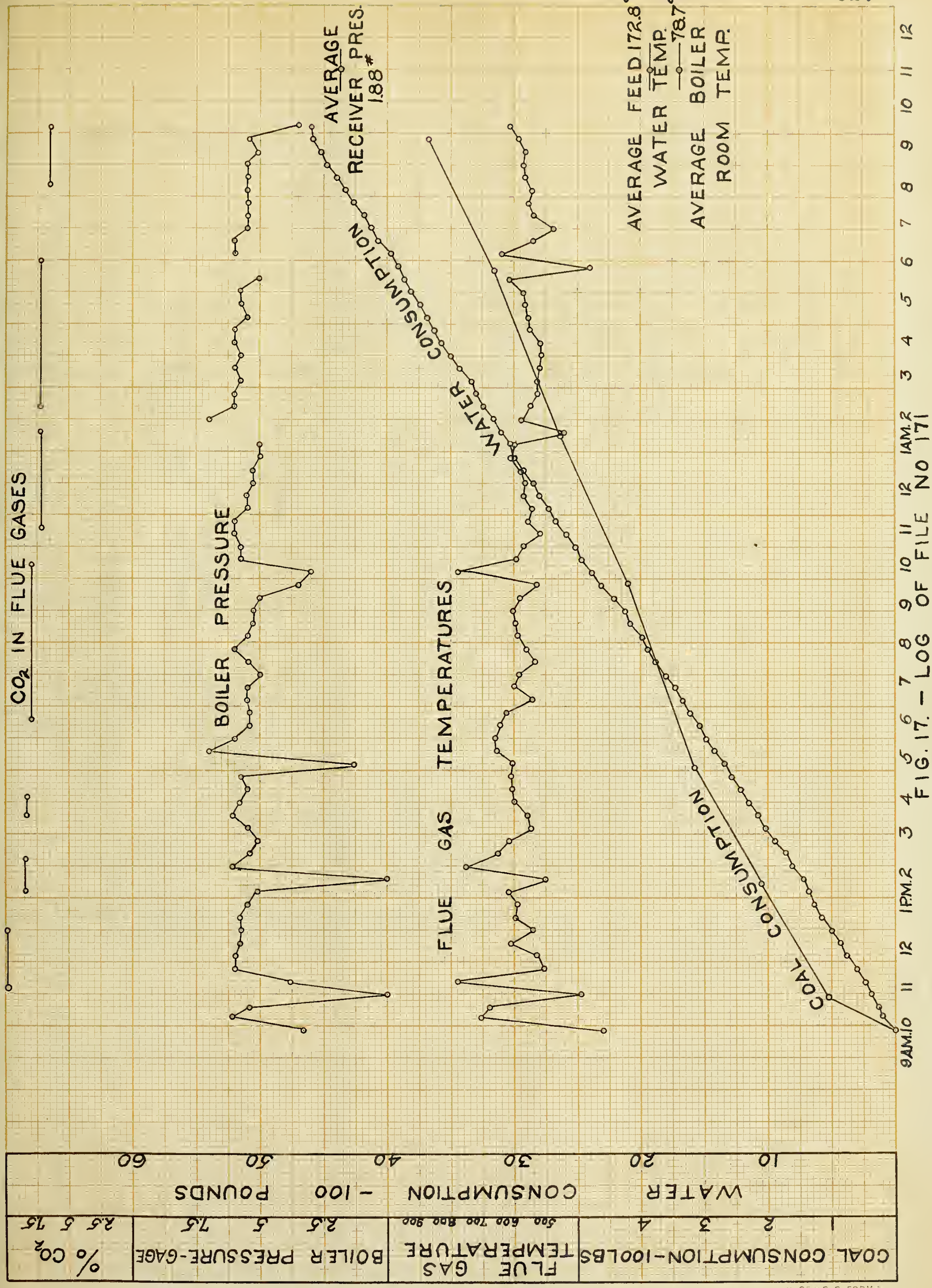

FIG. 17. — LOG OF FILE NO 171

Y OF DATA A

DRY COAL PER SQ.FT. GRATE SURFACE PER HR.	MOISTURE IN STEAM-%	FACTOR FOR QUALITY CORRECTION.		OST OF PORATION		FLUE GAS ANALYSIS		
			TOTAL WATER-LBS.	SURFACE PER HR ¢	PER 1000 LBS WATER FROM AND AT 212° ¢	CO_2 - PER CENT	O_2 - PER CENT	CO - PER CENT
5.5	0.99	.9906	1449	0	66.6	4.25	15.4	1.4
4.4	0.84	.9920	1906	9	61.5	6.50	13.9	0.5
5.5	1.11	.9894	2393	2	63.7	4.33	14.1	2.2
4.2	0.71	.9933	3218	5	54.3	7.83	11.4	0.5
5.0	0.98	.9906	3690	8	59.1	3.84	14.6	3.5
4.2	0.73	.9930	4585	6	54.2	7.87	11.5	0.3

SUMMARY OF DATA AND RESULTS

File Number	Date	Duration of Trial-Hrs.	Average Pressures		Average Draft Ins. of Water			Average Tempratures Degrees Fahrenheit				Wood Used-Lbs.	Coal Fired-Lbs.	Coal + Wood Equivalent-Lbs.	Coal + Wood Equiv.-Moist Fuel Equiv. of Resid.	Moisture in Coal-%	Total Dry Coal-Lbs.	Dry Coal-Carbon Equiv. in Residual-Lbs.	Dry Coal-Carbon Equiv in Ash & Residual-Lbs	Ash & Refuse-Lbs.	Residual Fuel-Lbs.	Dry Coal per Hr.-Lbs	Dry Coal per Sq. Ft. Grate Surface per Hr	Moisture in Steam-%	Factor for Quality Correction.	Water				Water per Hour					Economic Results				Efficiency %		Cost of Evaporation		Flue Gas Analysis		
			Boiler-Lbs. per Sq. In.	Receiver-Lbs. per Sq. In.	In Flue	Over Fire	In Ash Pit	External Air	Boiler Room	Feed Water	Flue Gases															Total Water-Lbs.	Water Actually Evaporated-Lbs.	Factor of Evap.	Equiv. Evap. from and at 212° F.-Lbs	Equiv. Evap. from and at 212° F.-Lbs	Equiv. Horse Power per Hour	Equiv. Evap. from and at 212 per Sq. Ft. W.H.S.	Mean Load-Sq. Ft. Radiating Surface	% of Rating Developed	Equiv. Evap. from & at 212° per Lb. Coal	Equiv. Evap. from & at 212° per Lb. Dry Coal	Coal per Hr. per 100 Sq. Ft. Rad. Surface	Dry Coal per Hr. per 100 Sq. Ft. Rad. Surface	Boiler & Furnace	Plant	Per 100 Sq. Ft. Rad. Surface per Hr ¢	Per 1000 Lbs Water from and at 212° ¢	CO_2-Per Cent	O_2-Per Cent	CO-Per Cent
164	2-29-08	9.73	5.51	1.85	.133	086	055	35.7	69.4	165.2	595	25	300	310	243	5.48	293	229	222	13.5	83	23.5	5.5	0.99	.9906	1449	1435	1.051	1509	155	4.49	3.92	517	64.7	6.20	7.10	4.84	4.56	52.3	47.8	2.0	66.6	4.25	15.4	1.4
165	2-29-08	10.42	4.05	1.75	.143	051	.020	35.7	69.4	164.6	590	30	420	432	296	5.48	408	278	274	6.0	159	26.7	4.4	0.84	.9920	1906	1890	1051	1987	190	5.50	2.66	632	58.8	6.71	7.25	4.49	4.21	53.1	51.7	1.9	61.5	6.50	13.9	0.5
168	3-6&7-08	15.47	6.07	1.96	.171	.092	.049	36.5	78.1	172.2	645	25	450	460	381	4.34	440	364	358	115	106	23.5	5.5	1.11	.9894	2393	2367	1.044	2471	160	467	4.05	532	665	6.48	6.90	4.62	4.42	508	49.4	1.9	63.7	4.33	14.1	2.2
169	3-6&7-08	16.78	5.24	1.97	.136	.054	026	36.5	78.1	166.9	557	30	525	537	441	4.34	514	421	408	21.0	130	25.1	4.2	0.71	.9933	3218	3196	1.049	3353	200	5.80	2.63	666	61.9	7.60	8.20	3.95	3.77	60.5	58.0	1.6	54.3	7.83	11.4	0.5
170	3-9&10-08	24.05	5.96	1.92	.137	.108	.049	39.4	78.7	176.4	591	25	600	610	543	4.20	584	519	504	38.0	91	21.6	5.0	0.98	.9906	3690	3655	1.040	3800	158	4.58	4.00	527	65.8	7.00	7.53	4.30	4.10	55.6	53.3	1.8	59.1	3.84	14.6	3.5
171	3-9&10-08	23.57	5.13	1.88	.127	.057	014	39.4	78.7	172.8	573	30	735	747	625	4.20	716	599	564	44.0	160	25.4	4.2	0.73	.9930	4585	4553	1.043	4749	202	5.83	2.66	671	62.7	7.60	8.43	3.95	3.79	64.1	60.1	1.6	54.2	7.87	11.5	0.3

SAMPLE CALCULATIONS.

Sample calculations for File 169 are as follows:-
(The figures in brackets refer to the items of the log sheet)

FUEL.

(21.1) Weight of fuel as fired + fuel equivalent of wood

$$(21) + (.4 \times (20) = 525 + (.4 \times 30) = 537 \text{ lbs.}$$

(21.2) Weight of fuel as fired + fuel equivalent of wood - moist fuel equivalent of residual fuel

$$(21.1) - \frac{(25) \times (37) \times 14600}{(46)}$$

$$= 537 - \frac{130 \times .6397 \times 14600}{12665} = 441 \text{ lbs.}$$

(23) Total dry fuel fired,

$$(21.1) \times \frac{100 - (22)}{100} = 537 \times \frac{100 - 4.34}{100} = 514 \text{ lbs.}$$

(23.1) Total dry fuel fired-dry fuel equivalent to carbon in residual fuel.

$$(23) - \frac{(37) \times (25) \times 14600}{(45)} = 514 - \frac{.6397 \times 130 \times 14600}{13090}$$

$$= 421 \text{ lbs.}$$

(23.2) Total dry fuel fired - dry fuel equivalent to the carbon in the "ash and refuse" and the carbon in the residual fuel.

$$(23.1) - \frac{(40) \times (24) \times 14600}{(45)} = 421 - \frac{.5527 \times 21 \times 14600}{13090}$$

$$= 408 \text{ lbs.}$$

FUEL PER HOUR.

(43) Dry fuel fired per hour.

(23.1) ÷ (1) = 421 ÷ 16.78 = 25.1 lbs.

(44) Dry fuel fired per sq. ft. of grate surface per hour

(43) ÷ (4) = 25.1 ÷ 6 = 4.2 lbs.

QUALITY OF STEAM.

(47) Moisture in steam

Water in separator ÷ (49) x 100 = 22.7 ÷ 3218 x 100 = .71

(48) Factor for correction for quality.

$$F = Q + P \frac{(T_1 - J_1)}{(H - J_1)} = .9929 + .0071 \frac{(187.3 - 135.4)}{(1148.5 - 135.4)}$$

$$= .9933$$

where Q = quality of moist steam,

P = proportion of moisture,

T_1 = total heat in water at temperature due to steam pressure.

J_1 = total heat of feed water due to its temperature

H = total heat of steam.

WATER.

(50) Water actually evaporated corrected for quality of steam.

(49) x (48) = 3218 x .9933 = 3196 lbs.

(51) Factor of evaporation.

$$\frac{H - h}{965.8} = \frac{1148.5 - 135.4}{965.8} = 1.049$$

where,

H = total heat of steam,

and, h = total heat of feed water due to its temperature.

(52) Equivalent water evaporated into dry steam from and at 212 degrees Fahr.

$(50) \times (51) = 3196 \times 1.049 = 3353$ lbs.

WATER PER HOUR.

(53) Equivalent evaporation per hour from and at 212 degrees Fahr.

$(52) \div (1) = 3353 \div 16.78 = 199.8$ lbs.

(53.1) Horse Power of boiler from item above.

$(53) \div 34.5 = 199.8 \div 34.5 = 5.8$ H.P.

(54) Equivalent evaporation per hour from and at 212 degrees Fahr. per sq. ft. of water heating surface,

$(53) \div (6) = 199.8 \div 75.87 = 2.63$ lbs.

(55) Mean load carried during test (steam condensed per sq. ft. of radiating surface per hour taken at 0.3 lb),

$(53) \div 0.3 = 199.8 \div .3 = 666$ sq. ft. radiation

(55.1) Load carried including external radiating surface of boiler,

$666 + 103.27 = 769.27$ sq. ft.

(56) Percentage of builder's rating developed,

$(55) \div (3) = 666 \div 1075 \times 100 = 61.9\%$

ECONOMIC RESULTS.

(57) Equivalent evaporation from and at 212 degs. Fahr. per lb. of fuel as fired,

$(52) \div (21.2) = 3353 \div 441 = 7.6$ lbs.

(58) Equivalent evaporation from and at 212 degs. Fahr. per lb of dry fuel,

$$(52) \div (23.2) = 3353 \div 408 = 8.2 \text{ lbs.}$$

(59) Fuel fired per hour per 100 sq. ft. radiating surface,

$$(21.2) \div \frac{(1) \times (55)}{100} = 441 \div \frac{16.78 \times 666}{100} = 3.95 \text{ lbs.}$$

(60) Dry fuel fired per hour per 100 sq. ft. radiating surface,

$$(43) \div \frac{(55)}{100} = 25.1 \div \frac{666}{100} = 3.77 \text{ lbs.}$$

EFFICIENCY.

(61) Efficiency of boiler and furnace; heat absorbed by the boiler per lb. of dry consumed fuel ÷ heating value of one lb. of dry fuel, where the dry fuel equivalent to the carbon in the ash and residual is subtracted from the total dry fuel fired.

$$\frac{(58) \times 965.8 \times 100}{(45)} = \frac{8.2 \times 965.8 \times 100}{13090} = 60.5\%$$

(62) Efficiency of plant; heat absorbed by boiler per lb. of fuel as fired where the moist fuel equivalent in/residual fuel is subtracted from the total fuel as fired,

$$\frac{(57) \times 965.8 \times 100}{(46)} = \frac{7.6 \times 965.8 \times 100}{12665} = 58\%$$

COST OF EVAPORATION.

(64) Cost of fuel per 100 sq. ft. of radiating surface per hour,

$$\frac{(63) \times 100 \times (59)}{2000} = \frac{8.25 \times 3.95 \times 100}{2000} = 1.63 \text{ cents.}$$

(65) Cost of evaporating 1000 lbs. of water from and at 212 degrees Fahr.

$$\frac{(63) \times 100}{2 \times (57)} = \frac{8.25 \times 100}{2 \times 7.6} = 54.3 \text{ cents.}$$

CONCLUSIONS.

In all of these tests only one kind of coal was fired, namely, Anthracite Egg Wyoming District, Pottsville, Pa. With the exception of duration of trial, there was no variation in the manner of conducting the tests, conditions being kept practically constant in all the tests as nearly as possible. Both boilers were run at the same time but independent of each other. The size of the orifices through which the steam was discharged was calculated to run the boilers at approximately 65% of their rating.

In the last two tests on the Arco boiler, the flue gas temperature immediately after firing became so high that it was necessary to remove the thermometer, consequently the record on the graphical log for those tests is incomplete. In the second test of the Mercer boiler there is a break in the flue gas temperature curve for the time in which the pyrometer was being calibrated.

The water consumption curve gives the actual evaporation for every twenty minutes. These readings were obtained by taking the amount of water fed into the boiler during the given interval corrected for the change of water level.

After the second firing the coal consumption for each test is practically constant. The short interval between the first and second firings is due to the thinness of the fuel bed which permitted air to pass through it freely andrequired a comparatively early firing of the second charge of fuel.

The higher percentage of CO_2 in the flue gases of the Mercer boiler was caused by the greater length of combustion chamber, thus allowing more perfect combustion.

Coal was fired in proportion to the grate surface, the Mercer boiler taking 105 pounds and the Arco 75 pounds at one firing.

Comparing the tests on the basis of dry coal fired per sq. ft. of grate surface per hour, the 16 hour test required less coal than the 8 hour test for the Mercer boiler and the same for the Arco while the 24 hour test in comparison with the 16 hour test took less coal for the Arco and the same for the Mercer. From this it appears that a longer test will in general require less dry coal per sq. ft. of grate surface per hour. However, the difference is so slight that it is practically negligible.

The following items were greater for the tests of longer duration with the exception of the Arco 16 hour test:-

Equivalent evaporation per hour from and at 212°F.

Mean load carried by boilers, consequently the percentage of builders rating developed. Equivalent evaporation from and at 212° F. per pound of dry coal. Efficiency of boiler and furnace.

The coal per 100 sq. ft. radiation was less the longer the test except that it was the same for the 16 and 24 hour Mercer tests.

The efficiency of the plant, however, steadily increased with the length of test.

Therefore, from the foregoing it appears that in testing

small steam boilers such as used for house heating purposes a test of from 16 to 24 hours duration gives a more accurate means of determining the evaporative performance of the boiler and the comparative value of different fuels.

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